Title: "AN ELECTRIC MOTOR MOVEMENT CONTROLLING METHOD, AN ELECTRIC MOTOR MOVEMENT CONTROLLING SYSTEM AND A COMPRESSOR."

The present invention relates to an electric motor movement con-
trolling method, an electric motor movement controlling system, as well as to
a compressor provided with a system according to the present invention.

Description of the Prior Art

Electric motor movement controlling systems are already known
from the prior art.

Control of electric motor movements is particularly important in
controlling motors applied to linear compressors, since with the latter the
stroke of the respective piston is not previously established. Because of this
constructive characteristic, the piston may collide with the respective stroke
end under certain circumstances, which undesirably results in noise, dam-
ages to the performance of the compressor or even the breaking of the com-
pressor.

A control of movements of electric motors usually monitors the
internal variables of the equipment itself, for instance, the position of the pis-
ton inside a cylinder, the capacity required for reaching a determined motor
demand. Systems of this nature may comprise, for example, compressors
coupled to cooling systems, wherein it is necessary to monitor the cooling
capacity of the compressor, and further prevent the respective piston from
colliding the stroke end, if cooling capacity suddenly changes.

Examples of this type of technique may be found in the docu-
ments US 5,432,176; US 5,496,153; US 5,450,521; and US 5,592,073. Ac-
cording to the teachings of this technique, a control over the piston stroke is
used, which constitutes a controller of the voltage imposed on the linear mo-
tor, re-fed by information about the piston position, basically estimated from
the current information supplied to the motor and the voltage induced at the
motor terminals.

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In these solutions, the piston stroke is controlled by taking the estimated position of the piston as a reference, which is calculated from the current and voltage at the motor terminals, but which leads to errors because of constructive variations of the motor, variations in temperature, which limits

5   the efficiency and the operation under extreme conditions of cooling capacity. Another deficiency of this type of solution is that the calculation of the average movement point of the piston is imprecise, basically caused by the average difference between the suction pressure and the discharge, and the elastic constant of the spring of the resonant system.

10   In cooling applications, for example, during the functioning, the electric motor together with the compressor will be subjected to various types of transients, such as opening the door of the cooling system, change of thermal charge, variation in the ambient temperature, opening or closing valves in the system, all of these thermo-mechanical transients have time

15   constants that are slow in comparison with the response time of the control, and do not cause disturbance in the displacement of the compressor, since the control manages to actuate before any effect is noticed.

The most abrupt phenomena to which the system will be subjected, are disturbances in the network voltage, and these disturbances may

20   affect the functioning of the compressor and, depending upon the condition of the compressor functioning and upon amplitude of the disturbance, a mechanical impact of the piston with the cylinder top may occur.

None of the proposed solutions analyzes the variations in network voltage and, therefore, they cannot guarantee for sure that the system

25   will correct in time the disturbances in the network, preventing the mechanical impact and oscillations on the maximum displacement that impair the efficiency of the system.

Objectives and Brief Description of the Invention

The proposed solution has the following objectives:

30   • Controlling the voltage level applied to electric motors in general;

• Controlling the movement of the piston of a linear motor;

• Monitoring the voltage level of the electric network directly and con-

cluding whether the voltage level applied to the motor should be altered or not;

- Controlling the stroke of the piston of a linear compressor, allowing the piston to advance as far as the end of its mechanical stroke, even under conditions of extreme load, without allowing the piston to collide against the cylinder top, even in the presence of external disturbances from the energy feed network;

- Controlling the stroke of the piston of a linear compressor, preventing oscillations in the maximum displacement of the piston, which impair the efficiency of the compressor, for any operation capacity of the compressor, even in the presence of external disturbances from the energy feed network;

- Implementing a simple solution for industrial-scale production.

These objectives are achieved by means of a method of controlling the movements of an electric motor, the electric motor being fed by a total voltage proportional to a network voltage, the method comprising the steps of: making a first measurement of the level of the network voltage at a first moment of measurement; making a second measurement of the level of network voltage at a second moment of measurement; calculating the value of the derivative of the voltage values measured in function of the first and the second moments of measurement, in order to obtain a value of a proportional network voltage; and altering the value of the total voltage fed to the motor, proportionally to the value of the value of the proportional network voltage.

The method further comprises steps of altering the value of the total voltage in function of the difference between the value of the proportional network voltage calculated in a present cycle of the network voltage and the value of the proportional network voltage calculated in the previous cycle of the network voltage; or altering the value of the total voltage in function of the difference between the value of the proportional network voltage calculated in a present semi-cycle of the network voltage and the value of the proportional network voltage calculated in the previous semi-cycle of the net-

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network voltage.

A further objective of the present invention is achieved by means of an electric motor movement controlling method, the electric motor being fed by a total voltage proportional to the network voltage, the method com-
5   prising the steps of: measuring the network voltage at a first moment of measurement; measuring the network voltage at a second moment of measurement, the second moment of measurement being different from the first moment of measurement and the second measurement of the network voltage being carried out at a voltage level different from the level of the first
10   measurement of the network voltage; measuring the lag time between the occurrence of the measurement of the first moment of measurement and the occurrence of the measurement of the second moment of measurement; comparing the lag time with the pre-established time; altering the value of the total voltage proportionally to the value of the proportional network voltage.

15   Still a further objective of the is achieved by means of an electric motor movement controlling system controlled by an electronic control central, the electric motor being fed by a total voltage controlled by the electronic control central, the total voltage being proportional to the network voltage, the electronic control central comprising a voltage-detecting circuit, the voltage-
20   detecting circuit detecting the network voltage, the electronic control central measuring a first measurement of level of the network voltage at a first moment of measurement, and measuring a second measurement of level of the network voltage at a second moment of measurement; the electronic control central calculating the value of the derivative of the values of the network
25   voltage measured in function of the times of measurement measured and obtaining a value of a proportional network voltage; the electronic control central altering the value of the total voltage to a value of corrected total voltage, proportionally to the value of the proportional network voltage.

Brief Description of the Drawings
30   The present invention will now be described in greater detail with reference to an embodiment represented in the drawings. The figures show:

- Figure 1 is a block diagram of the system of the present inven-

tion, illustrating the respective interconnection upon application to a compressor and a cooling system;

     - Figure 2 is a block diagram of the system of controlling the movement of a piston according to the present invention upon application to

5   a linear compressor;

     - Figure 3 is a block diagram of the algorithm for control of the system for controlling the movement of a piston of the present invention;

     - Figure 4 illustrates the control network of the system of controlling the movement of a piston of the present invention;

10   - Figure 5 is an electric diagram of a voltage-detecting circuit used in the system of the present invention;

     - Figure 6 shows a graph of an input and output signal of the generator by the voltage-detecting circuit, for various levels of input voltage (nominal voltage, nominal voltage + 10%, nominal voltage − 10%);

15   - Figure 7 shows a graph of the lag time of the output signal of the voltage-detecting circuit in function of the variation of the network voltage;

     - Figure 8 illustrates the points where the network voltage is measured according to the teachings of the present invention;

     - Figure 9 illustrates two different situations of network voltage,

20   and the points of measurement made; and

     - Figure 10 illustrates a particular situation where the teachings of the present invention are applied.

Detailed Description of the Figures

     The present invention relates to a system, as well as a method of

25   controlling an electric motor, being particularly applicable for controlling movements of a piston in a linear compressor.

     As can be seen in figures 1 and 2, the system of controlling movements of a piston according to the present invention comprises an electronic control 12, which monitors a network voltage V_{AC} and controls a total

30   voltage V_T applied to an electric motor that drives a compressor 14, which may be applicable to a cooling system 15.

     The electronic control 12, comprises an electronic control central

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10 which, by means of a gate circuit 21 controls the conduction time of a switch set 11 (preferably *TRIACs*), to control the total voltage level V_T.

In figure 2, one can see that the control system of the present invention comprises, associated to the electronic control central 10, a voltage

5   detecting circuit 50, which is electrically connected to the network voltage V_{AC}, so that the respective value will be measured before its level is controlled by the switch set 11.

With this configuration the electronic control central 10 can control the level of the total voltage V_T applied to the motor, proportionally to the

10   level of the network voltage V_{AC}, and thereby prevent the occurrence of an overvoltage or undervoltage in the feed network, that might cause the compressor 14 to behave in an unexpected way.

In order to implement the use of the system and monitor the network voltage V_{AC} and thus decide whether to interfere or not in the level of

15   the total voltage V_T, one should implement the control algorithm illustrated in figure 3, according to the control network illustrated in figure 4.

As can be seen in figure 3, the value of the total voltage V_T comprises the sum or subtraction of a value of a piston voltage V_P and a correction voltage V_V from the equation:

20          $V_T = V_P \pm V_V$.

The value of the piston voltage V_P is obtained from the values supplied by an external device, for example, a reference signal REF, which may indicate to which extent the compressor piston should be moved, especially in the cases where the teachings of the present invention are applied

25   on linear compressors, since in the latter the cooling capacity will depend upon the excursion amplitude of the respective piston. The value of the reference signal may be a DC level transmitted to the electronic control device 10. In this way, and position of reference DP_{REF} of the piston is established.

Another variable necessary to establish the value of the piston

30   voltage V_P is obtained by calculating the maximum desirable excursion point which the piston should advance without the risk of the latter colliding at the respective stroke end. Preferably, the value of the piston voltage V_P is ob-

tained by storing the value of the piston voltage V_P of the previous cycle. The value of maximum displacement DP_{MAX} should, therefore, be previously established based on the characteristics of the compressor 14.

5   Once the values of reference displacement DP_{REF} and maximum displacement DP_{MAX} have been obtained, the value of the piston voltage V_P can be obtained, since the latter is a function of the difference between the values obtained, that is to say, between the calculated error E_{DP}.

The other component of the total voltage V_T, the value of the correction voltage V_V, will be obtained according to the teachings of the present

10   invention, by comparing the value of the network voltage V_{AC} with a previously established value to conclude that there is a need for correction of the respective value, that is to say, the value of the correction voltage V_V will be the difference itself between the voltage expected to be read and the network voltage V_{AC}. In this way, in the cases where the value of the network voltage

15   V_{AC} is within the expected limits, the value of the correction voltage V_V will be null, since there is no need to alter the value of the network voltage V_{AC}.

As can be seen in figures 8 and 9, this measurement principle is carried out by adopting a fixed value of voltage V_0 (or established voltage level V_0) and counting the required time for the network voltage VAC to reach

20   this level. This, in reality, is the same as measuring the derivative of the network voltage V_{AC} close to zero, to estimate the value of the network voltage.

Putting this into equations, the following conclusion is reached:

$$V_{AC} = f\left(\frac{\partial V_0}{\partial t}\right), V_{AC} \text{ being proportional to } \frac{\partial V_0}{\partial t_0}$$

25   For constant ∂V_0 :

$$V_{AC} = f\left(\frac{1}{\partial t_0}\right)$$

V_{AC} is inversely proportional to ∂t_0

$$V_{AC1} = f\left(\frac{\partial V_0}{\partial t 1_0}\right)$$

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$$V_{AC2} = f\left(\frac{\partial V_0}{\partial t2_0}\right)$$

For constant ∂V_0:

$$V_{AC1} = f\left(\frac{1}{\partial t1_0}\right)$$

$$V_{AC2} = f\left(\frac{1}{\partial t2_0}\right)$$

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Thus, one may conclude that the value of the above demonstrated network voltage V_{AC} may be calculated on the basis of the established voltage level V_0 and by taking as a reference the value V_{AC1} and V_{AC2} illustrated in figure 9. In this way, by taking, for instance, the value of V_{AC1} as a
10   reference, one may conclude that the value V_{AC2} would be below the level of network voltage V_{AC} desired for a determined application, and the value of the total voltage V_T should be corrected. The value V_{AC} taken as a reference will be the value of voltage of the previous cycle or the mean of the previous cycles, which results in that the value of the voltage taken as a reference will
15   not be constant, since the objective is to correct an oscillation of a cycle of the network for the next cycle.

As demonstrated above, considering that for a constant voltage level by adopting the established voltage level V_0 equal for the two measures, thus having constant ∂V_0, it is sufficient to measure only the time
20   passed between two points measured by the voltage detecting circuit 50 and to detect which is the real voltage level from an equation or table of values.

In order to reach the voltage value necessary to correct the total voltage V_T, the value of the correction V_V should be obtained, which, in practice, will be a proportional network voltage V_{AC}'; on the other hand, the re-
25   spective value will be directly related to the value of the input voltage V_{AC}. In the same way as explained above, the value of the network voltage V_{AC} should be obtained from measurements of the previous network voltage V_{AC},

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or from the mean of the measurements of the previous network voltages V_{AC}.

Mathematically, the value of the proportional network voltage V_{AC}' is reached by the following operation:

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$$V_{AC}' = f\left(\frac{\partial V_0}{\partial t}\right)$$

As can be seen from the equation, the value of the proportional network voltage V_{AC}' is obtained by means of the derivative of voltage values obtained in function of the time passed between the measurements.

In order to implement such an equation in practice, it is enough
10   to carry out two measurements of voltage and two measurements of time, as exemplified in figure 10, so that one can proceed with the respective derivative, that is to say, one should preferably measure the network voltage V_{AC} at a first moment of measurement t_{10} to define a first measurement of level V_{t0} and then measure the network voltage V_{AC} at a second moment of meas-
15   urement t_{20}, defining a second measurement of level V_{t20}.

Once these values have been obtained, one proceeds with the equation below:

$$V_{AC}' = f\left(\frac{V_{t20} - V_{t10}}{t_{20} - t_{10}}\right)$$

20   that is to say, by subtracting from the first and second measurements of level V_{t10}, V_{t20} and dividing the result by the subtraction of the values of the first and second moments of measurement t_{10}, t_{20}, and the value ∂t is obtained by subtracting the values of the first and second moments of measurement t_{10}, t_{20}.

25   From this control algorithm the readings of the input voltage should be stored at every semi-cycle of the network voltage V_{AC} and compare the present reading with the previous one (or with the previous ones), and alter the value of the output to compensate for the network voltage V_{AC}, thus preventing a variation in the maximum piston displacement from occur-
30   ring, since this variation might lead to a mechanical impact of the piston with the cylinder top or to a loss of efficiency of the system.

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For instance, one may opt for carrying out a number of measurements on different cycles of network voltage V_{AC} and store the obtained values in the electronic control central 10, carrying out the derivative of the obtained values subsequently in order to reach a value of the proportional

5   network voltage V_{AC}'.

In order to implement the use of the concepts of the present invention, a method is provided by which the network voltage V_{AC} can be monitored and conclude that there is a need to make some adjustment in the level of the total voltage V_T.

10   The method includes the steps of measuring the network voltage V_{AC} at a first moment of measurement $t1_0$, and designated such a measurement as first level measurement V_{t10}.

Then the network voltage V_{AC} should be measured at a second moment of measurement $t2_0$. In the same way, the value of these measure-

15   ments may be designated as a second level measurement V_{t20}.

Once these values are obtained as described above, the value of the derivative of the voltage values is calculated and measured in function of the measurement times $t1_0$, $t2_0$, to obtain the value of a proportional network voltage V_{AC}' and, finally, alter the value of the total voltage V_T fed to the mo-

20   tor proportionally to the value of the proportional network voltage V_{AC}'.

One of the ways of proceeding, in practice, with the step of obtaining the value of the proportional network voltage V_{AC}' may be by means of the following steps:

A lag time t_D is measured between the occurrence of the meas-

25   urement of the first moment of measurement $t1_0$ and the occurrence of the measurement of the second moment of measurement $t2_0$. In this way, one can know which maximum level of the network voltage V_{AC} is required in order to conclude that there is a need for correction in the value of the total voltage V_T.

30   For this purpose, it is enough to compare the lag time t_D with a pre-established time t_P, the latter being determined by the electronic control central 10, and one may proceed with the elevation of the total voltage V_T if

the lag time t_D is longer than the pre-established time t_P, or with reduction of the total voltage V_T if the lag time t_D is shorter than the pre-established time t_P.

In practice, it is recommendable to consider the value of the pre-established time t_P as the measurement of the lag time t_D of the previous cycle or the mean of the previous cycles.

The simple comparison of the lag times t_D with the pre-established time t_P is opted when the conditions are more appropriate for this, but one may carry out the above steps when the circuits used in the embodiment demand the need to proceed with the derivative described before.

As far as the system for implementing the method of the present invention is concerned, it should comprise the electronic control central 10 to control the electric motor and the voltage detecting circuit 50 to measure the value of the network voltage V_{AC}.

As described in the method, the electronic control central 10 will make the first level measurement V_{t10} of the network voltage V_{AC} at a first moment of measurement $t1_0$, making the second level measurement V_{t20} of the network voltage V_{AC} at the second moment of measurement $t2_0$, and these measurements may be carried out as times goes by and as the cycles of the network voltage V_{AC} take place.

The derivative of the values of the network voltage V_{AC} measured in function of the times of measurement $t1_0$, $t2_0$ measured and the obtention of the value of the proportional network voltage V_{AC}' will be carried out by the electronic control central 10, which, in function of the value of the network voltage V_{AC} will alter the value of the total voltage V_T to a value of corrected total voltage V_T' to prevent the piston from going beyond the foreseen point and to prevent impacts.

The voltage detecting circuit 50 should comprise the first voltage detecting circuit 51 to detect the first level of network voltage V_{M1} and the second voltage detecting circuit 52 to detect the second level of the network voltage V_{M2}.

Preferably, the first voltage detecting circuit 51 is adjusted to

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measure the first level of network voltage V_{M1} at the time of the respective passage by a zero level (or zero of the voltage ZT) and the second voltage detecting circuit 52 to measure the second level of network voltage V_{M2} between the zero level of the network voltage V_{AC} and the maximum level of the

5   network voltage V_{ACM}. In this way, two different measurements of level are obtained, and thus it is possible to proceed with the derivative of the measured values.

The lag time t_D is registered between the occurrence of the measurement of the first level of the network voltage V_{M1} and the occurrence

10   of the measurement of the second level of the network voltage V_{M2}. These measurements are carried out by the voltage detecting circuit 50, which will transmit the respective occurrences to the electronic control central 10. A time counting device comprised in the electronic control 12 compares the lag time t_D with the pre-established time t_P, and alters the total voltage V_T propor-

15   tionally to the lag time t_D. The value of the total voltage V_T will be raised to a value of corrected total voltage V_T' if the lag time t_D is longer than the pre-established time t_P and reduced to a value of corrected total voltage V_T' is the t_D is shorter than the pre-established time t_P. When the value of the lag time t_D is equal to the pre-established time, it will not be necessary to make an

20   alteration in the total voltage V_T, since, in this case, the network voltage V_{AC} will be in ideal conditions. In other words, in these conditions, when the lag time t_D is null, the value of the total voltage V_T will be the value of the piston voltage V_P.

Within the teachings of the present invention, one can see in fig-

25   ures 2 and 5 that the first and second voltage detecting circuits 51, 52 are directly connected to the network voltage V_{AC}, the respective outputs ZT and TR being fed to the electronic control device 10.

The first voltage detecting circuit should preferably be configured as illustrated in figure 5, that it so say, a configuration where the zero level of

30   the voltage ZT of the network voltage V_{AC} is detected. In this case, the output ZT of this circuit will oscillate between 0 V and Vcc, which in the example of figure 6 is of 5V, a difference existing between the value of 5V and the read

signal (see curve 55) due to the drop in voltage on the diode D1 (Scales 0.5 V/div – 0.5 ms/div). In this way, the signal ZT may be directly interpreted by the electronic control circuit 10.

The second voltage detection circuit 52 comprises a voltage di-
5   vider R_2/R_3, which lowers the level of the network voltage V_{AC} to an adequate level to be processed by the electronic control central 10. This may be seen in the curves illustrated in figure 6, which correspond, respectively, to the measurements made with voltage levels of 242V (see curve 62), 220V (see curve 63) and 198V (see curve 64), these curves illustrating, respectively, a
10   situation of V_{AC} in overvoltage, expected voltage and undervoltage, and the value of the voltage VT should be mediated/corrected whenever there is os-cillation from a cycle to another.

A comparator 56 of the second voltage detecting circuit 52 will detect the passage of the level of the network voltage V_{AC} by a point that is
15   pre-determined and controlled by the reference voltage Vref, to signalize at the output TR that the reference voltage level has been reached. The result of this is the generation of square waves 62', 63' and 64', which correspond, respectively, to the values of the network voltage V_{AC} measured. The com-parator 56 may be embodied, for instance, by using an operational amplifier
20   or another type of equivalent device.

The voltage comparator 53 will generate a square wave having a transition moment, the lag time t_D being measured between the occurrence of the first level of the network voltage V_{M1} and the transition moment.

This may be observed in figure 6, where the lag times t_{D1}, t_{D2}, t_{D3}
25   are illustrated, and which correspond to the examples of voltage at a level of 242V (curve 62), 220V (curve 63) and 198V (curve 64), respectively.

The voltage values measured by the first and second voltage detecting circuits 51, 52 correspond to the first level of the network voltage V_{M1} and to the second level of network voltage V_{M2} described above, and are
30   interpreted in the way foreseen in the method of the present invention. One can see, in this example, that the value of the first level of the network volt-age V_{M1} is equal to zero (see indication with reference 65 in figure 6).

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With respect to the first and second moments of measurement $t1_0$, $t2_0$, they will be registered from the moment of detection of the zero level of the voltage ZT and the detection of the reference voltage TR, and should be proceeded with the counting of the time between the respective occur-

5   rences so that the lag time t_D is compared with the pre-established time t_P and alter the total voltage VT proportionally to the lag time t_D. As can be seen in figure 6 (see indication 65), in this example, the value of the first moment of measurement $t1_0$ is equal to zero, and the pre-established time t_P will be the mean of the defined time t_D of the previous cycle or the mean of the pre-

10   vious cycles.

Another way to embody the voltage detecting circuit 50 may comprise, for example, instead of the fist voltage detecting circuit 51 operating in conjunction with the second voltage detecting circuit 52, to detect the zero level of the voltage ZT and the reference level TR, a pair of circuits simi-

15   lar to the second voltage detecting circuit 52. In this option, it is enough that the reference value of the comparator 56 can simply be adjusted at two different levels, so that the measurement said first and second levels of the voltage V_{M1}, V_{M2} can be made at the first and second moments of measurement $t1_0$, $t2_0$ and proceed with the derivative of the measurements and find

20   the proportional network voltage V_{AC}'.

As a further way of embodying the voltage detecting circuit 50 to obtain the values of the first and second levels of the voltage V_{M1}, V_{M2} at the first and second moments of measurement $t1_0$, $t2_0$, one may foresee the use of a converter D/A. In this solution, the same measurements foreseen in the

25   embodiments described above should be proceed, and the interpretation of the means made by the electronic control central 10 should be adapted, which will receive the digital number corresponding to the measurement made by the converter D/A.

One of the ways of detecting which is the value of the network

30   voltage V_{AC} from the measurement of the first and second voltage levels V_{M1}, V_{M2} is that one may opt for storing a table of values foreseen in the electronic control central 10 and from the value of the lag time t_D measured one can

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conclude which is the value of the network voltage V_{AC}.

Thus, the second table below may accompany the example of figure 7.

V_{AC} [V]	t_D [ms]
246	2.36
242	2.63
220	3.00
198	3.57
176	5.00

5   One can note, in this example, that the value of the pre-established time t_P is of 3.00 ms and the lag time t_D varying between 2.36 (characterizing overvoltage) and 5.00 (characterizing undervoltage).

The control over the total voltage VT may be made together with the control over the piston voltage V_P, supplied by a piston position control. In

10   this way, one can actuate at the same time with an internal control, for example, of a system involving a compressor with a control of the level of the network voltage V_{AC}, complementing the systems and resulting in a much more efficient and safe control.

Thus, with the teachings of the present invention, one prevents

15   oscillations in the network voltage V_{AC} from interfering with the situation of the electric motor, which, for instance, might cause mechanical collision of the piston with the top of the cylinder of the linear compressor, thus improving the reliability and the working life of the compressor, besides improving functioning stability of the compressor, preventing loss of efficiency caused

20   by variation in the maximum displacement of the piston.

A preferred embodiment having been described, one should understand that the scope of the present invention embraces other possible variations, being limited only by the contents of the accompanying claims, which include the possible equivalents.